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A Laboratory Study of OCC Flotation for Removal of Model Stickie Particles

T.J. Heindel and K.T. Hodgson

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A Laboratory Study of OCC Flotation for Removal of Model Stickie Particles

Theodore J. Heindel
Institute of Paper Science and Technology
500 10th Street, NW
Atlanta, GA 30318
ted.heindel@ipst.edu

Kevin T. Hodgson
Paper Science and Engineering
University of Washington
Box 352100
Seattle, WA 98195-2100
hodgson@u.washington.edu

EXECUTIVE SUMMARY

Flotation was evaluated as a potential unit operation for stickie contaminant removal from brown fiber grades (i.e., OCC). It was shown that for conditions of this study, stickies can be effectively removed by flotation. However, using a bench-scale flotation cell, fiber loss in this study varied from 7 to 17%.

This work was completed using a commercially-built bench-top flotation cell, a model brown fiber system (virgin linerboard), and model stickie materials (wax and hot melt). The model system was used to control the initial contaminant concentration and size distribution, and to identify which sizes are most effectively removed.

Flotation in a bench-top cell is effective at removing model stickie particles in the size ranges that are not being removed by current OCC screening and cleaning operations. Future work will focus on pilot trials operating under typical OCC mill conditions to determine if the bench-top results are applicable to mill settings.

APPLICATION STATEMENT

Flotation is shown to be an effective option for removing model stickie contaminants from brown fiber grades.

ABSTRACT

A laboratory flotation cell was used to remove model stickie particles (wax and hot melt) from a model brown fiber (virgin linerboard) system. The model systems were used to control the contaminant concentration as well as the contaminant size distribution. The size ranges addressed here are those that are currently not being removed in typical OCC cleaning and screening operations. It is shown that both model wax and hot melts are effectively removed by flotation from the brown fiber system. The overall particle removal efficiency was unaffected by changes in various process conditions. However, the process conditions can have a significant effect on fiber loss (i.e., yield), which is an important factor in OCC operations.

KEYWORDS

Contaminants, Flotation, OCC, Recycling, Stickies

INTRODUCTION

The use of flotation as a unit operation in the pulp and paper industry can be divided into two general types: (i) dispersed air flotation, and (ii) dissolved air flotation. Dispersed air flotation is commonly used in flotation deinking applications, where relatively large bubbles form bubble-particle aggregates with hydrophobic particles (i.e., inks, toners, etc.) and carry them to the surface for removal. It is *selective* in that it separates contaminant particles from the desired fiber. Dissolved air flotation (DAF) is typically employed in water clarification situations, where air is dissolved into the process stream under pressure. When the pressure is reduced, numerous fine bubbles come out of solution and float "rafts" of contaminant particles to the surface for eventual separation. It is critical in DAF that all the particulate matter is flocculated together, before nucleation of air bubbles. Because of this fact, DAF removes all solid particles and is not considered to be selective. In this study, dispersed air flotation was investigated as one possible means of selectively removing model stickie contaminants from repulped old corrugated containers (OCC). Dispersed air flotation will be the only type of flotation discussed for the remainder of this paper, and will simply be referred to as “flotation”.

Stickies are a general term of recovered paper contaminant that can be classified into two types (1, 2). “Primary stickies” are formed by the direct breakdown and coarse dispersion of adhesive materials in the stock preparation and recycling process. “Secondary stickies” are either very finely dispersed adhesive materials, or fine tacky particles formed by the interaction of naturally occurring compounds in the wood fibers themselves and papermaking additives. Papermakers often cite stickies as one of the greatest barriers to increasing secondary fiber usage across nearly all paper grades (1). It is estimated that the total cost of these contaminants in lost production time, lost raw material, final product downgrading, and land fill costs could be as high as $700 million annually within the United States alone (3).

Mechanical and chemical means are commonly used to remove stickie contaminants from the process stream. In OCC operations, contaminants are typically removed with successive passes through various screens and cleaners. Dispersion may also be used to mechanically modify contaminant size for more effective removal or pacification (4). Additives may also be used to enhance contaminant removal (5-9) or pacification (10). However, even after apparently successful OCC processing, stickies still find their way to the paper machine, where they can cause a variety of operational and product quality problems (11).

Recently, Gupta et al. (12) analyzed multiple samples of cleaned OCC after processing in a typical OCC system. It was determined that the contaminant sizes being passed to the paper machine were in the range of 20-500 μm, with the majority in the 50-200 μm size range. Most stickie contaminants are also hydrophobic. Therefore, with the given size range identified by Gupta et al. (12) and the hydrophobicity of many stickie contaminants, flotation is a logical choice for an additional separation process that OCC manufacturers can use to remove troublesome stickie materials before they get to the paper machine.

Stickies removal with flotation equipment typically found in deinking operations has been attempted. McEwen (13) has suggested that wax removal by flotation may be possible. Galland et al. (14) completed laboratory and pilot plant flotation trials using waxed paper. They concluded that flotation was very successful at removing wax from waxed paper and board grades, but fiber loss was as high as 15-20%. The use of flotation to remove other stickie types, such as hot melts and pressure sensitive adhesives (PSAs), has also been shown to be successful (15-20).

This paper describes laboratory results using flotation to remove stickie materials from brown fiber grades. A model brown fiber system and two different model stickies are used in this study. This allowed for control of the contaminant concentration and size distribution in the feed streams. Details are presented below.

EXPERIMENTAL PROCEDURES

The flotation trials completed in this study focused on fiber loss and contaminant removal from brown fiber (representing OCC). The experiments were completed in a bench-top flotation cell using model OCC brown fiber (virgin linerboard) with or without added model stickie contaminants (wax and hot melt). The flotation cell conditions will first be described; then, the procedures for fiber loss and contaminant removal studies will be outlined.

Flotation Procedures

The flotation trials completed in this study utilized a Wemco flotation cell (EIMCO Process Equipment, Salt Lake City, UT). A schematic of the basic unit is shown in Fig. 1. It consisted of a 3.5 L plastic tank, an impeller and stabilizer, and a hollow stainless steel shaft. It was equipped with a variable speed rotor (300-1500 RPM) and a gas inlet valve. With the gas inlet open to the atmosphere, the aeration rate is a function of the impeller speed. However, in this study, the gas inlet was connected to pressurized air and metered into the cell. Therefore, the aeration rate was independently controlled from the impeller speed.

For a flotation experiment, the Wemco flotation cell was charged with 3 L of stock at a specified consistency (with or without added contaminants). The flotation temperature was typically maintained at ambient conditions (~21°C). The pH of the system was adjusted to 9 and a frother (Triton™ X-100) was added to created a stable foam during flotation. Triton™ X-100, henceforth referred to as TX-100, is an octyl phenol ethoxylate (9.5 moles EO) nonionic surfactant. It acts as a moderate foaming agent over a wide range of pH conditions. The impeller was set to a desired speed and turned on with the air line closed to mix the system for a preflotation time of 1 minute. The air flow was then turned on with the air flow rate set to its desired value. Flotation was then performed for 10 minutes.

Fiber Loss Procedures

Fiber loss was determined for various flotation conditions using a model OCC brown fiber system without added contaminants. A virgin linerboard, containing mainly Douglas Fir and Pine, was selected as the model fiber system to provide a uniform fiber source for the flotation trials. Since this was a virgin furnish, it was assumed that it was contaminant-free with regard to stickies. Therefore, the rejects from a fiber loss flotation trials were collected and the dry weight was determined. The fiber loss was then calculated as follows:

$$\text{Fiber Loss (\%)} = \frac{\text{Solids Mass in Rejects}}{\text{Solids Mass in Feed}} \times 100 \qquad [1]$$

At least five flotation trials were conducted for each fiber loss experiment to determine an average fiber loss for each test condition.

Contaminant Removal Procedures

Contaminant removal efficiencies from the model OCC system were determined by spiking the model fiber system with a model stickie contaminant of a known size distribution (either a wax or a hot melt) and then performing flotation. This assumes all contaminant particles are completely separated from the fiber and neglects fiber-contaminant detachment effects. This was done to focus solely on the flotation process.

Samples of the flotation feed and accepts were collected to make low basis weight handsheets (~20-25 g/m^2) to eliminate any two-sidedness effects. The handsheets were formed on filter paper (VWRbrand Grade No. 415) using a Büchner funnel. The filter paper had a pore size of 25 μm to ensure no contaminants of interest were lost in the handsheet filtrate.

The bleaching and staining procedure of Gupta et al. (12) was then used to enhance the contrast between the contaminants and the brown fiber. This procedure called for bleaching the handsheets with hypochlorite and then staining them with Sudan IV (a red stain). Handsheet drying between steps was completed under ambient conditions to ensure no particle size modification. It was also independently verified that the bleaching and staining procedures did not alter the particle size in the handsheets. This procedure allowed image analysis to determine the particle concentration in the feed and accepts. The particle removal efficiency was defined as:

$$\text{Removal Efficiency (\%)} = \left(1 - \frac{\text{Particle Accept Concentration}}{\text{Particle Feed Concentration}}\right) \times 100 \qquad [2]$$

For a removal efficiency in a given particle size range, only those particles in that range were used in Eq. [2]. An overall removal efficiency was also defined using Eq. [2], where the overall particle concentration was used. Additionally, to reduce the influence of basis weight variations from handsheet to handsheet, the particle concentration was determined on an od fiber basis. The coefficient of variation of the particle concentration from handsheet to handsheet in the various feed samples was typically less than 9%, and was assumed to be a good compromise between statistically significant results and excessive analysis time. The accept handsheets had relatively low particle counts, which increased their COV values, but the removal efficiencies were repeatable.

Model wax particles of a known size distribution were generated using a microcrystalline wax that is used in curtain coating operations (Astro 3040 – melting point: 65-88°C, specific gravity: ~0.9 at 25°C) and the procedures described in Bose et al. (21). Figure 2 shows the size distribution of the model wax contaminants that were added to the virgin linerboard samples. This size range encompasses the range identified by Gupta et al. (12) for contaminants found in "clean" OCC samples. Wax particles were then collected after formation and stored in cold DI water. Approximately 1 g of 25% by weight of the wax particles was added per liter of 1% model OCC fiber, and then well mixed before flotation trials were initiated. A single flotation trial with 1% fiber and added wax particles, but without air injection (i.e., no flotation removal), verified that the mixing imparted by the Wemco flotation cell did not have a significant effect on wax particle breakup or coalescence.

Model hot melt particles (HL-7500, H.B. Fuller, Inc. – softening point: 113°C, specific gravity: 0.989 at 25°C) of a known size distribution were also investigated in this study. These particles were generated by freezing hot melt pellets in liquid nitrogen and then disintegrating them in a Waring blender. The blender was run intermittently for approximately 15 minutes to generate particles of various sizes. Prolonged grinding (greater than 15 minutes) led to hot melt flocculation and blender binding. The ground hot melt particles were then fractionated using Tyler screens and then recombined to form the desired particle size distribution. Figure 2 also includes the resulting model hot melt particle size distribution used in this study. These particles were stored dry for use. Approximately 0.25 g of the model hot melt was added per liter of 1% fiber slurry and well mixed before flotation.

RESULTS

Since the focus of this study was to determine if flotation is feasible to remove model stickie contaminants from a model brown fiber system, a set of baseline reference conditions were first identified. These baseline experiments were completed using the Wemco flotation cell to establish a reference fiber loss and contaminant removal efficiency from the model systems considered here. Selected parameters were then altered to determine their effect on the reference values. In all cases, the main objective was to minimize fiber loss and maximize contaminant removal. Future work will use this information to identify trial conditions in pilot plant work. In what follows, the reference conditions will first be discussed; then, the effects of foamer concentration, fiber consistency, impeller speed and air injection rate, and flotation temperature will be addressed.

Reference Conditions

Table 1 summarizes the reference conditions for the initial flotation trials. The fiber type (virgin linerboard), flotation time (10 min), preflotation time (1 min), and pH (9) were fixed for all trials completed in this study. The remaining parameters were varied after reference fiber loss and contaminant removal efficiencies were determined.

A series of flotation trials *without* added model contaminants were completed at the reference flotation conditions to determine a reference fiber loss of 17.2±3.3%. This fiber loss would be unacceptable in any mill OCC flotation process. Parameter variations (described below) were completed to minimize this loss.

The flotation removal efficiency of model wax particles in shown in Fig. 3 for the reference flotation conditions. Both the feed and accepts had some particles in the size ranges greater than 250 μm. However, these particle concentrations were not statistically significant to allow for the accurate determination of removal efficiencies in these ranges. Therefore, flotation removal efficiencies are shown for particle diameters less than 250 μm. Additionally, particles larger than 250 μm would typically be removed in standard cleaning and screening systems in most OCC operations.

All wax particle size ranges reported in Fig. 3 have a removal efficiency greater than 60%. The overall removal efficiency ranged from 78 to 91% for the three trials. The differences between trials is attributed to slight variations in the image analysis procedures for each trial. The procedures were subsequently standardized and refined for the remaining flotation trials. This figure does show that for wax particles in the size range identified by Gupta et al. (12), flotation may be effectively used for their removal.

Figure 3 also shows the removal efficiency for a flotation trial using the model hot melt particles and the reference flotation conditions. Efficiencies in the size range greater than 250 μm are again not meaningful due to the small number of feed and accept particles in these ranges, and thus are not shown. For each hot melt particle size range shown in Fig. 3, the removal efficiency is greater than 80%, and the overall removal efficiency is 85.4%.

The similarity in the removal efficiencies for both the model wax and model hot melt particles is expected in part because the contact angles for both model contaminants are similar (98 degrees for the model wax and 96 degrees for the model hot melt). Improved flotation performance could be realized by further optimizing the flotation chemical and physical parameters. Variations in the flotation cell physical parameters will now be discussed (variations in the chemical parameters like surfactant type, collector chemistry, etc. are not addressed here).

Effect of Foamer Concentration

The effect of foamer concentration was determined by varying the TX-100 concentration while keeping the remaining flotation parameters at their reference conditions (Table 1). Figure 4 displays the fiber loss as a function of TX-100 concentration, where at least five flotation trials were completed at each TX-100 concentration. The error bars represent one standard deviation in the fiber loss data. Increasing the TX-100 concentration increases the fiber loss from the Wemco flotation cell. As the TX-100 concentration increases, the fluid surface tension decreases until the critical micelle concentration (CMC) is reached. For TX-100, the CMC is approximately 0.2 g/L of fluid (0.02 g/(g od fiber) for a 1% consistency system). The decrease in surface tension reduces the bubble size and creates a more dense, watery foam, which enhances fiber loss. This phenomenon has been recently described for flotation of bleached fiber grades (22, 23). At the lowest TX-100 concentration addressed here (0.0033 g/(g od fiber); 3.3 kg/metric ton), a fiber loss of 8.3±1.0% was observed. This condition had such a low concentration of TX-100 that froth generation did not last the entire 10 minutes of the flotation run, but stopped after approximately 7-8 minutes. This also contributed to the decrease in fiber loss.

Flotation trials with virgin linerboard samples spiked with model wax particles were also completed to determine the particle removal efficiency at the *lowest* TX-100 concentration. Figure 5 shows that the model wax particle removal efficiency is very good, even though the TX-100 concentration is reduced to 0.0033 g/(g od fiber). All particles less than 250 μm have a removal efficiency of more than 90%, and the overall removal efficiency from each trial is 95% or greater. This is superior to the reference conditions (Fig. 3). It is hypothesized that a change in bubble size results in the improved removal efficiency at the lower TX-100 concentration. At this low concentration, the fluid surface tension is higher than during the reference conditions. This should provide a slightly larger equilibrium bubble size (24) that may be more conducive to bubble-particle aggregate formation for the size of contaminant particles found in the feed stock. Hence, the formation of a potentially more stable bubble-particle aggregate increases the removal efficiency even though the fiber loss (and foam generation) has been decreased.

Since the lowest TX-100 concentration produced a minimum fiber loss and an improved particle removal efficiency, all subsequent flotation trials were conducted at this TX-100 concentration.

Effect of Fiber Consistency

The effect of fiber consistency on fiber loss and particle removal was investigated by varying the fiber consistency between 0.5 and 1.2%. As a reference, typical consistency ranges for flotation deinking cells generally fall in the range of 0.8-1.2%. The TX-100 concentration was fixed at 0.0033 g/(g od fiber) (3.3 kg/metric ton). All other flotation parameters were fixed at the reference values.

As shown in Fig. 6, the 1% consistency flotation trial using virgin linerboard resulted in the lowest recorded fiber loss for this unbleached fiber system. The total mass of fiber lost during the 0.5% consistency trial was lower than the 1% consistency trial, but the percent fiber loss is lower for the latter condition. Most flotation deinking operations are run at a maximum consistency to increase fiber throughput and minimize process equipment size. However, the results in Fig. 6 seem to indicate that fiber loss (i.e., yield) would suffer in the system considered here.

In addition to higher fiber loss at the 1.2% consistency, the mixing was not very uniform. Dead zones (i.e., regions of very little mixing) in the corners of the Wemco flotation cell were observed. The presence of these dead zones would also lower particle removal efficiency, since the injected air bubbles would have difficulty mixing with the contaminants in these regions. The size of these dead zones also appears to be a function of consistency. An initial maximum consistency of 1.5% was attempted in this study, but the dead zones were so large and strong that mixing occurred only near the impeller of the Wemco flotation cell and little, if any, foam was generated. When the consistency was reduced to 1.2%, although there were still dead zones, enough mixing took place to generate foam. The dead zones were not observed during the 0.5 and 1% trials.

Since the lowest fiber loss occurred at a consistency of 1%, further model contaminant removal trials at the other consistencies were not conducted.

Effect of Impeller Speed and Air Injection Rate

The effects of impeller speed and air injection rate were determined by varying the impeller speed from 600 to 1500 RPM, and the air injection rate from 6 to 12 Lpm. As previously shown, the fiber loss was minimized at the lowest TX-100 concentration (0.0033 g/(g od fiber); 3.3 kg/metric ton), while the particle removal rate did not suffer. Therefore, the TX-100 concentration was maintained at the lowest value used in this study. All other parameters were fixed at the reference conditions (Table 1).

Figure 7 shows the fiber loss as a function of impeller speed for three different air injection rates. At a fixed impeller speed, the fiber loss increases as the air injection rate increases; a maximum fiber loss occurs at 12 Lpm, the maximum air injection rate addressed in this study. This can be partially explained through observations of the foam generation time. At 6 Lpm, foam generation in the Wemco flotation cell did not last the entire 10 minutes of flotation. In contrast, at 12 Lpm, foam generation continued for almost the entire 10 minutes of the flotation trial. Hence, the increase in fiber loss as air injection rate increased is likely due to an increase in the foam generation time. (This has recently been confirmed by additional studies in our laboratories.)

When the air injection rate is fixed, the fiber loss is a maximum at 900 RPM. In general, the foam generation time decreases as the impeller speed increases. However, at 600 RPM, dead zones are observed in the corners of the flotation cell, reducing mixing and fiber loss. At 900 RPM, even though foam generation time has decreased, the mixing in the flotation cell has improved considerably, which results in an increase in fiber loss. At 1200 RPM, mixing is very good, but the foam generation time is less than that observed at 900 RPM, reducing the fiber loss. At 1500 RPM, the mixing is also very good, but the fiber loss decreased with an air injection rate of 6 Lpm and increased with an air injection rate of 9 Lpm. This is attributed to the amount of water in the foam, with the 9 Lpm condition producing a more watery foam.

From these studies, the fiber loss appears to be a complex function of air injection rate and impeller speed, both of which influence the tank mixing conditions and the foam structure. The highest fiber loss occurs when the entire flotation cell is being thoroughly mixed and the foam generation time is maximized (i.e., 900 RPM and 12 Lpm).

Although fiber loss was lowest when the impeller speed was set to 600 RPM and the air injection rate was 6 Lpm, the flotation cell contained dead zones. This resulted in poor mixing with the rest of the flotation cell. Therefore, contaminant removal in these areas would not be very effective, and thus experiments were not conducted for this specific impeller speed and air injection rate.

Selected contaminant removal studies were completed at various impeller speeds and air injection rates, using model wax particles as the contaminants. These results are shown in Fig. 8. The contaminant removal efficiencies for all of the impeller speed and air injection rate combinations are quite similar. The removal efficiencies had a maximum in the 100-200 μm range, with greater than 98% removal efficiency. The overall removal efficiency for each test condition was also very similar and greater than 95% in all cases examined.

Effect of Flotation Temperature

A series of flotation trials were completed at an elevated temperature to determine the effect of temperature on fiber loss and particle removal efficiency. Model wax particles were used in these experiments. If the temperature was elevated beyond the melting point of the wax particles (~65°C for the wax used in this study), the wax particle size distribution could be altered substantially. Therefore, flotation trials were initiated at a stock temperature of 49°C. This temperature was reached by heating 3 L of the desired stock in a water bath until the slurry temperature reached the desired limit. The slurry was then immediately transferred into the Wemco flotation cell, which was well-insulated during these trials. Even with good insulation, the temperature was not constant during the flotation trials because the injected air bubbles act as a cooling mechanism. After a 10 minute flotation time, the average slurry temperature was 43°C. In these trials, all flotation parameters were fixed at their reference values (Table 1), with the exception of flotation temperature and the TX-100 concentration, which was set at the lowest value used here (0.0033 g/(g od fiber); 3.3 kg/metric ton).

Five flotation trials of uncontaminated virgin linerboard were conducted at the elevated temperature to determine average fiber loss. An average value of 8.9±0.3% was recorded. This value is essentially unchanged from the fiber loss obtained at room temperature (8.3±1.0%). Therefore, fiber loss is not a function of flotation temperature for the conditions addressed here.

Two additional flotation trials with added model wax particles were conducted at the elevated temperature to determine its effect on contaminant removal efficiency. The removal efficiencies for each trial are shown in Fig. 9 and the results are very similar to those obtained at room temperature (i.e., Fig. 5). The overall removal efficiencies for both the room temperature trials (95.0-97.0%) and the elevated temperature trials (94.7-96.7%) are equivalent. Based on these observations, the temperature has a negligible effect on the flotation particle removal for the conditions of this study. However, note that a significant condition employed here is that the temperature must be maintained below the melting point of the contaminant particles for this conclusion to be valid.

Parameter Variation Summary

Table 2 summarizes the fiber loss and overall particle removal efficiency for the parameters addressed in this study. As shown, the changes in the various process conditions can have a significant effect on the fiber loss, but the overall contaminant removal efficiencies are greater than 95% for all conditions when the TX-100 concentration is at 0.0033 g/(g od fiber) (3.3 kg/metric ton). It should be remembered that these results are for a bench-scale flotation cell, and are not necessarily an accurate indication of the *absolute* level of fiber loss in a production scale flotation cell. This would also include the measured removal efficiencies. Theses results are, however, useful for relative comparisons between different operating conditions.

CONCLUSIONS

A laboratory flotation cell was used to remove model stickie contaminants from a model brown fiber system consisting of virgin softwood linerboard. It was shown that flotation is very effective at removing the model contaminants. The removal efficiencies did not vary significantly when selected process conditions were changed. However, these same process changes did have a significant effect on the level of fiber loss. Generally, a minimum level of foaming agent was most favorable for particle removal and fiber loss considerations. Conditions of adequate mixing of stock and air in the cell, which did not over-promote foam generation, were seen to produce the best results with regard to keeping fiber loss to a minimum. The results of this study suggest that there may be promise for enhanced removal of wax and hot melt stickie contaminants from brown fiber grades by employing dispersed air flotation as an additional unit operation to existing OCC recycling plants.

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TABLES

Table 1: Reference conditions for the Wemco flotation cell.

Parameter	Reference Conditions
Fiber Type	Virgin Linerboard
Flotation Time	10 minutes
Preflotation Time	1 minute
Consistency	1%
pH	9
Flotation Temperature	~21°C
TX-100 Concentration	0.01 g/(g od fiber) (3.3 kg/metric ton)
Impeller Speed	900 RPM
Air Injection Rate	6 Lpm

Table 2: Fiber loss and overall particle removal efficiency summary. Only the given parameters are changed from the reference conditions unless otherwise noted.

Parameter	Fiber Loss (%)	Overall Particle Removal Efficiency (%)
Reference Conditions	17.2	78-91
TX-100 Concentration of 0.0033 g/(g od fiber)	8.3	95-97
900 RPM, 12 Lpm†	15.5	97.3
1200 RPM, 9 Lpm†	8.7	97.3
1200 RPM, 6 Lpm†	8.2	96.0
1500 RPM, 6 Lpm†	7.3	95.7
Elevated Temperature††	8.9	95-97

† TX-100 concentration was set at 0.0033 g/(g od fiber)

†† Flotation temperature was increased to 43-49°C and the TX-100 concentration was set at 0.0033 g/(g od fiber)

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Figure 5: Model wax removal efficiency at a TX-100 concentration of 0.0033 g/(g od fiber).

Figure 6: The effect of flotation consistency on fiber loss.

Figure 7: The effect of impeller speed and air injection rate on fiber loss.

Figure 8: Model wax removal efficiency for various impeller speed and air injection rate combinations.

Figure 9: Model wax removal efficiency at an elevated flotation temperature.

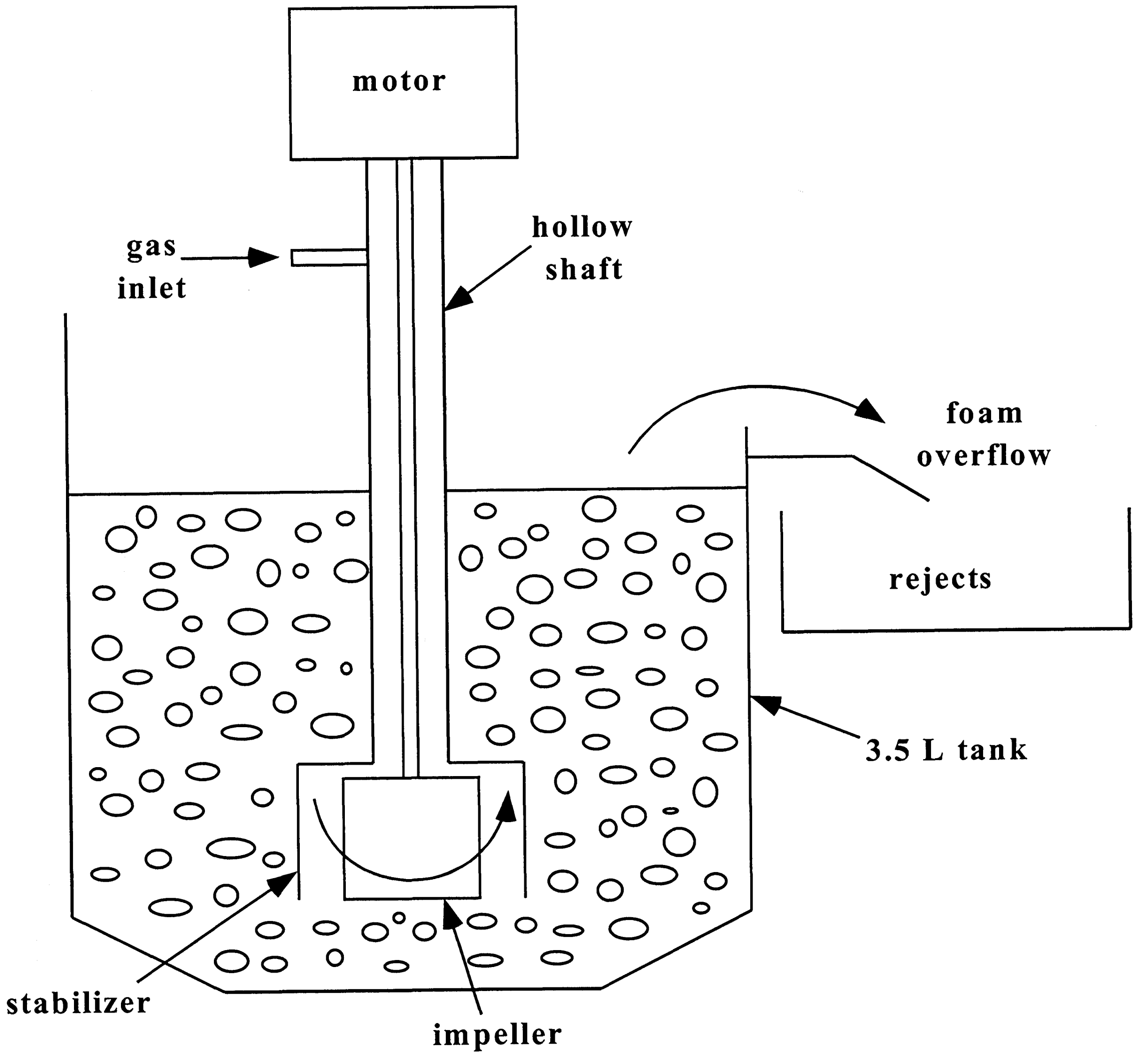
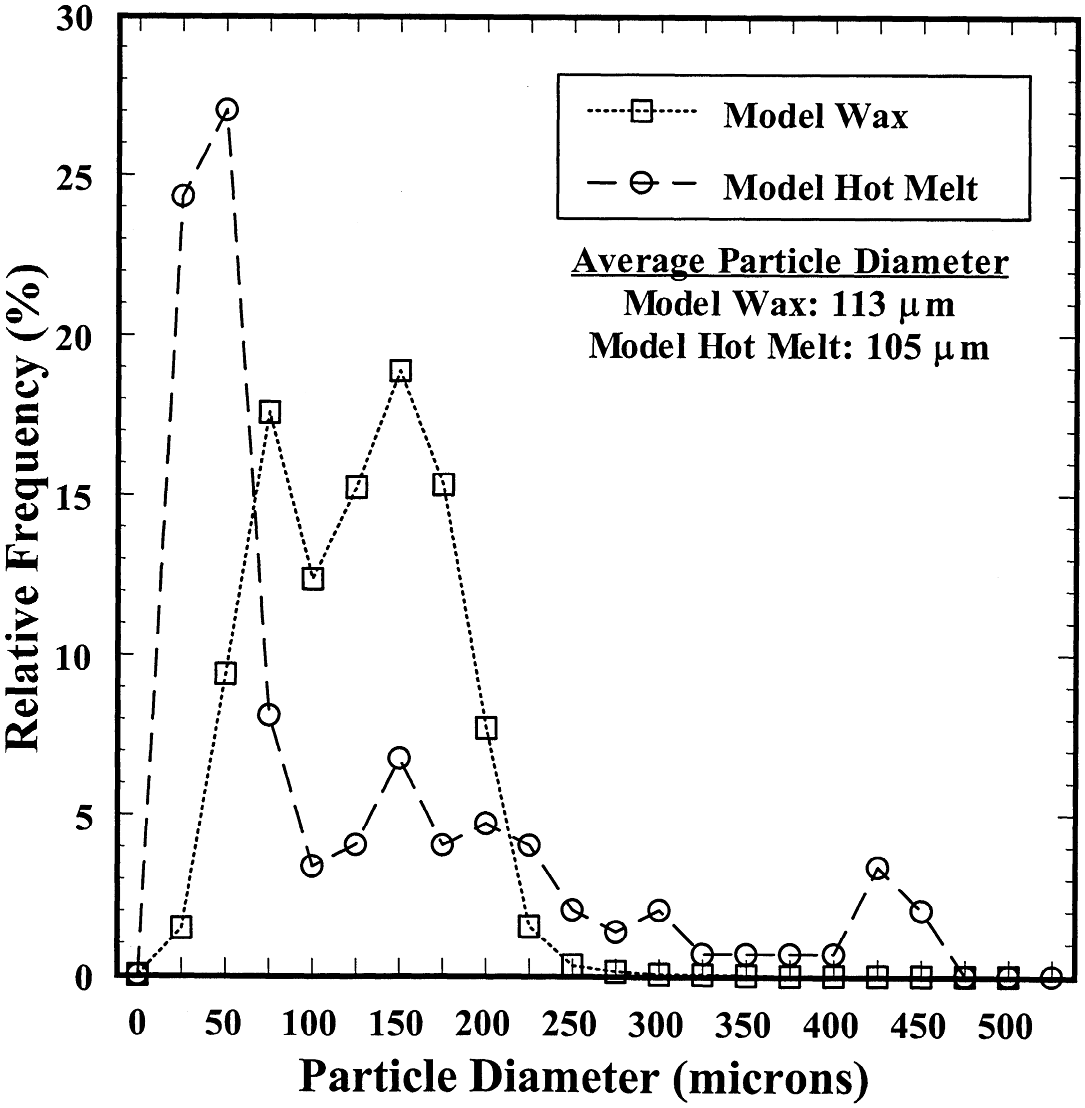
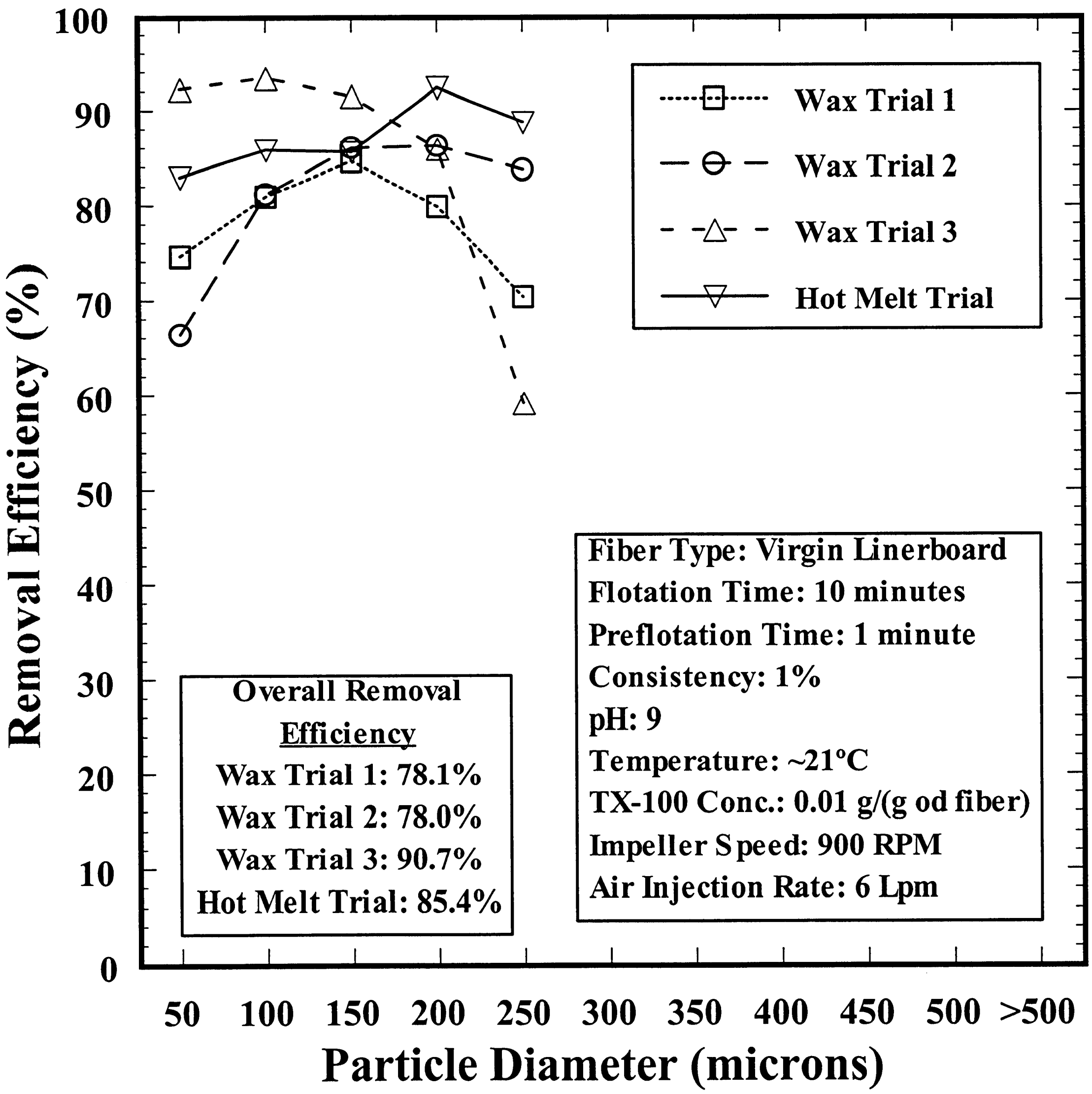

motor
gas inlet
hollow shaft
foam overflow
rejects
3.5 L tank
stabilizer
impeller

Figure 1



30
25
20
15
10
5
0
Relative Frequency (%)
Model Wax
Model Hot Melt
Average Particle Diameter
Model Wax: 113 μm
Model Hot Melt: 105 μm
0
50
100
150
200
250
300
350
400
450
500
Particle Diameter (microns)

Figure 2



Removal Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
Wax Trial 1
Wax Trial 2
Wax Trial 3
Hot Melt Trial
Fiber Type: Virgin Linerboard
Flotation Time: 10 minutes
Preflotation Time: 1 minute
Consistency: 1%
pH: 9
Temperature: ~21°C
TX-100 Conc.: 0.01 g/(g od fiber)
Impeller Speed: 900 RPM
Air Injection Rate: 6 Lpm
Overall Removal Efficiency
Wax Trial 1: 78.1%
Wax Trial 2: 78.0%
Wax Trial 3: 90.7%
Hot Melt Trial: 85.4%
50 100 150 200 250 300 350 400 450 500 >500
Particle Diameter (microns)

Figure 3

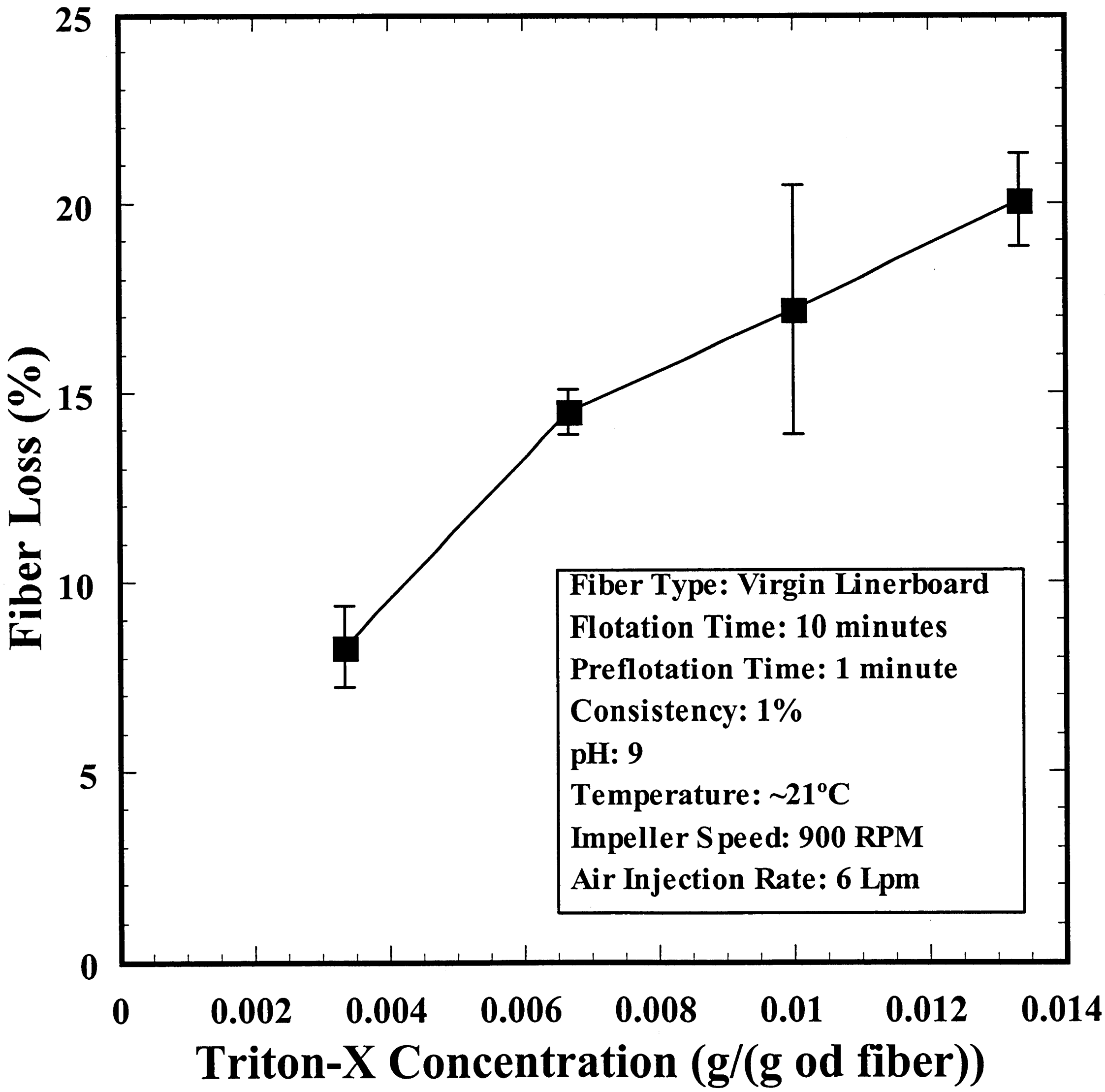

Fiber Loss (%)
25
20
15
10
5
0
0
0.002
0.004
0.006
0.008
0.01
0.012
0.014
Triton-X Concentration (g/(g od fiber))
Fiber Type: Virgin Linerboard
Flotation Time: 10 minutes
Preflotation Time: 1 minute
Consistency: 1%
pH: 9
Temperature: ~21°C
Impeller Speed: 900 RPM
Air Injection Rate: 6 Lpm

Figure 4

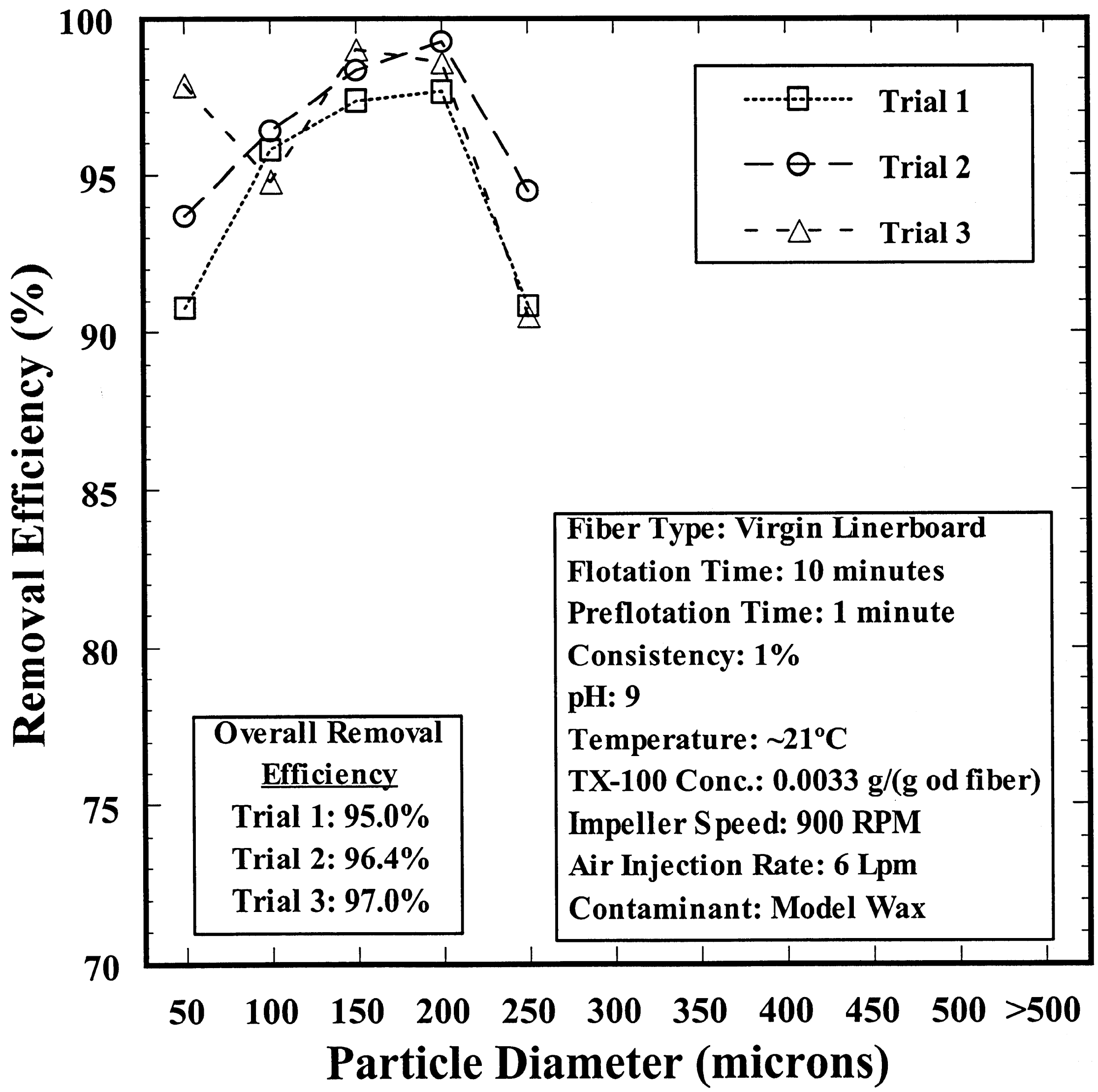
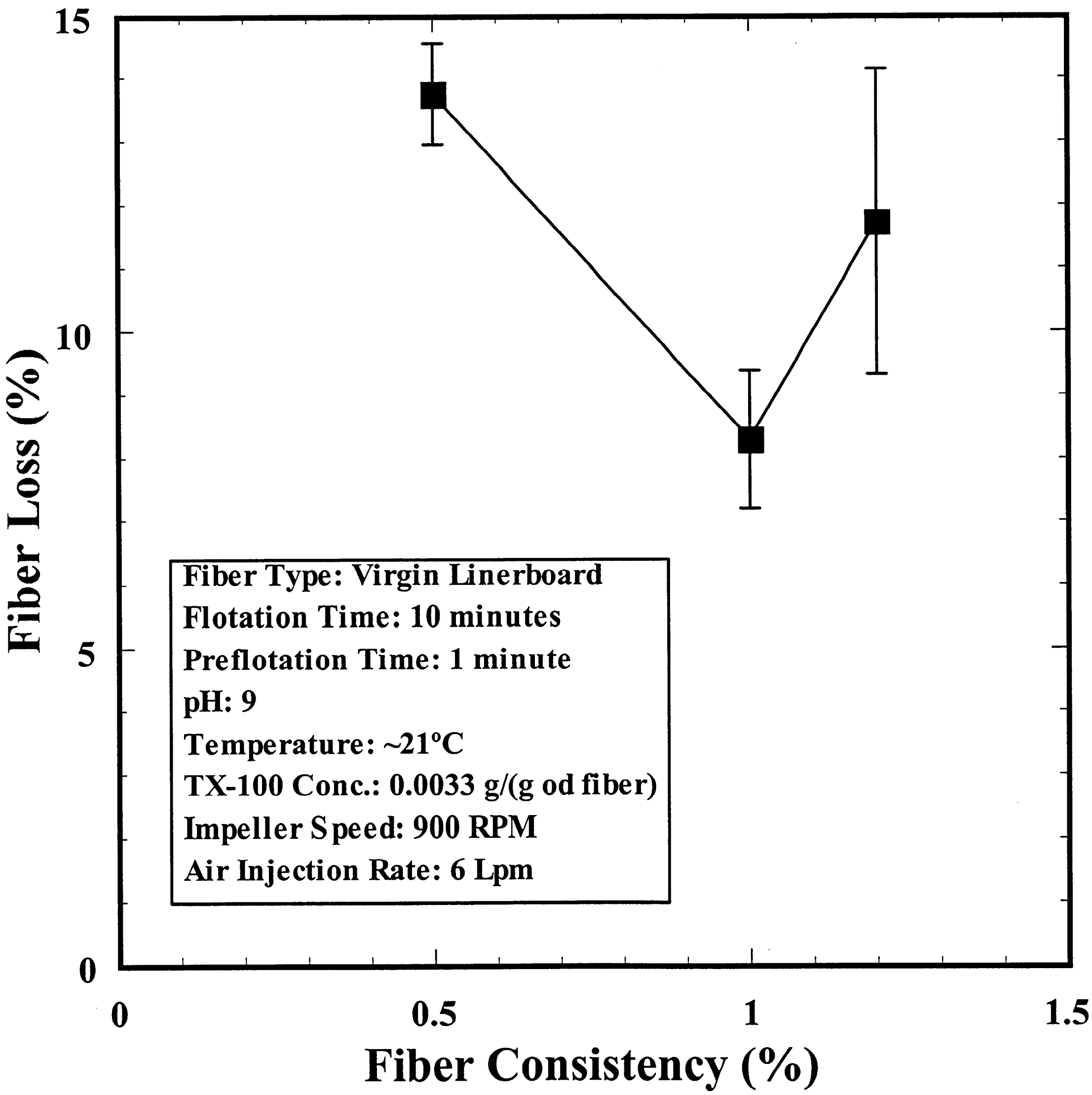
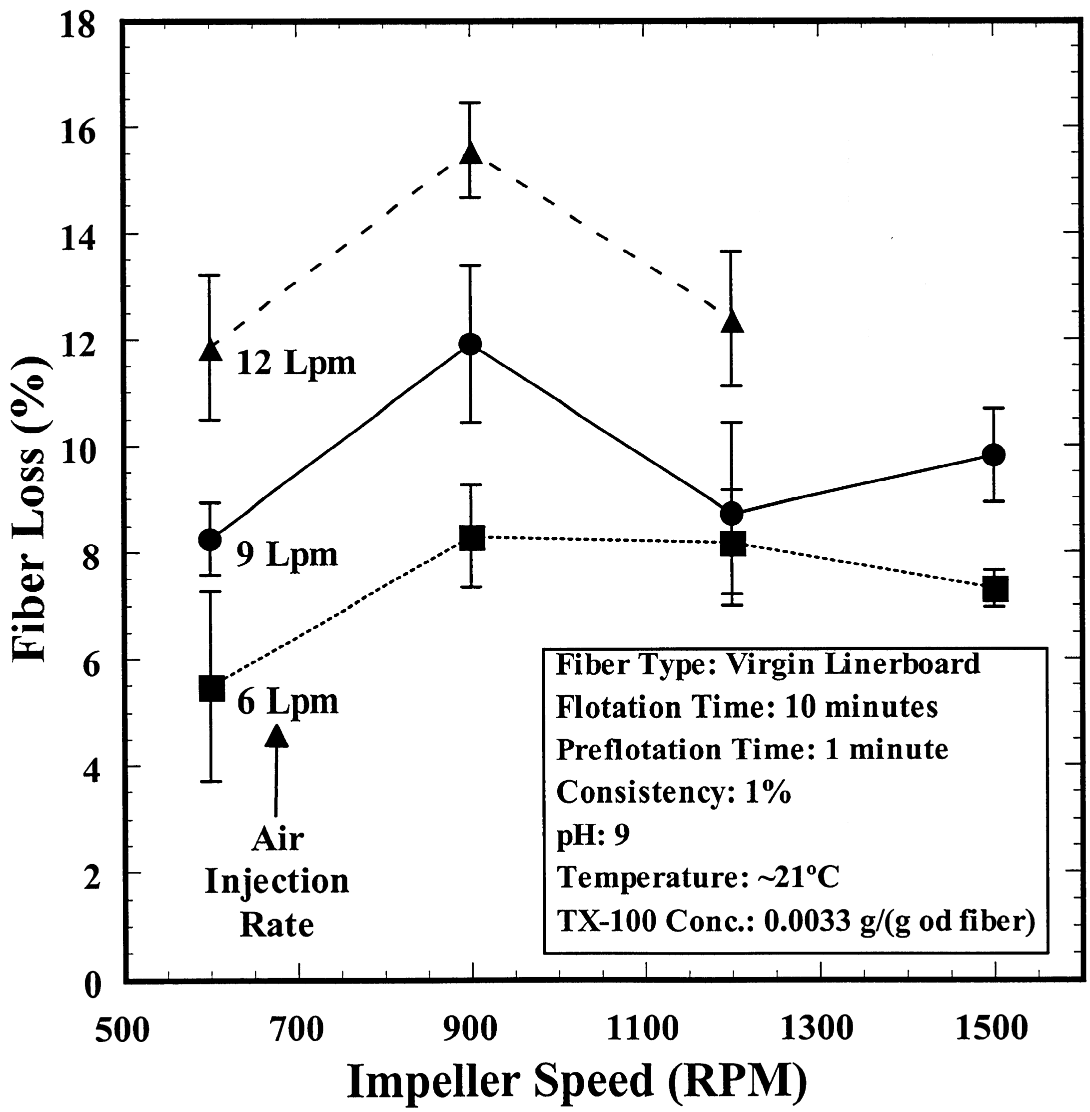

100
95
90
85
80
75
70
Removal Efficiency (%)
Trial 1
Trial 2
Trial 3
Fiber Type: Virgin Linerboard
Flotation Time: 10 minutes
Preflotation Time: 1 minute
Consistency: 1%
pH: 9
Temperature: ~21°C
TX-100 Conc.: 0.0033 g/(g od fiber)
Impeller Speed: 900 RPM
Air Injection Rate: 6 Lpm
Contaminant: Model Wax
Overall Removal Efficiency
Trial 1: 95.0%
Trial 2: 96.4%
Trial 3: 97.0%
50
100
150
200
250
300
350
400
450
500
>500
Particle Diameter (microns)

Figure 5



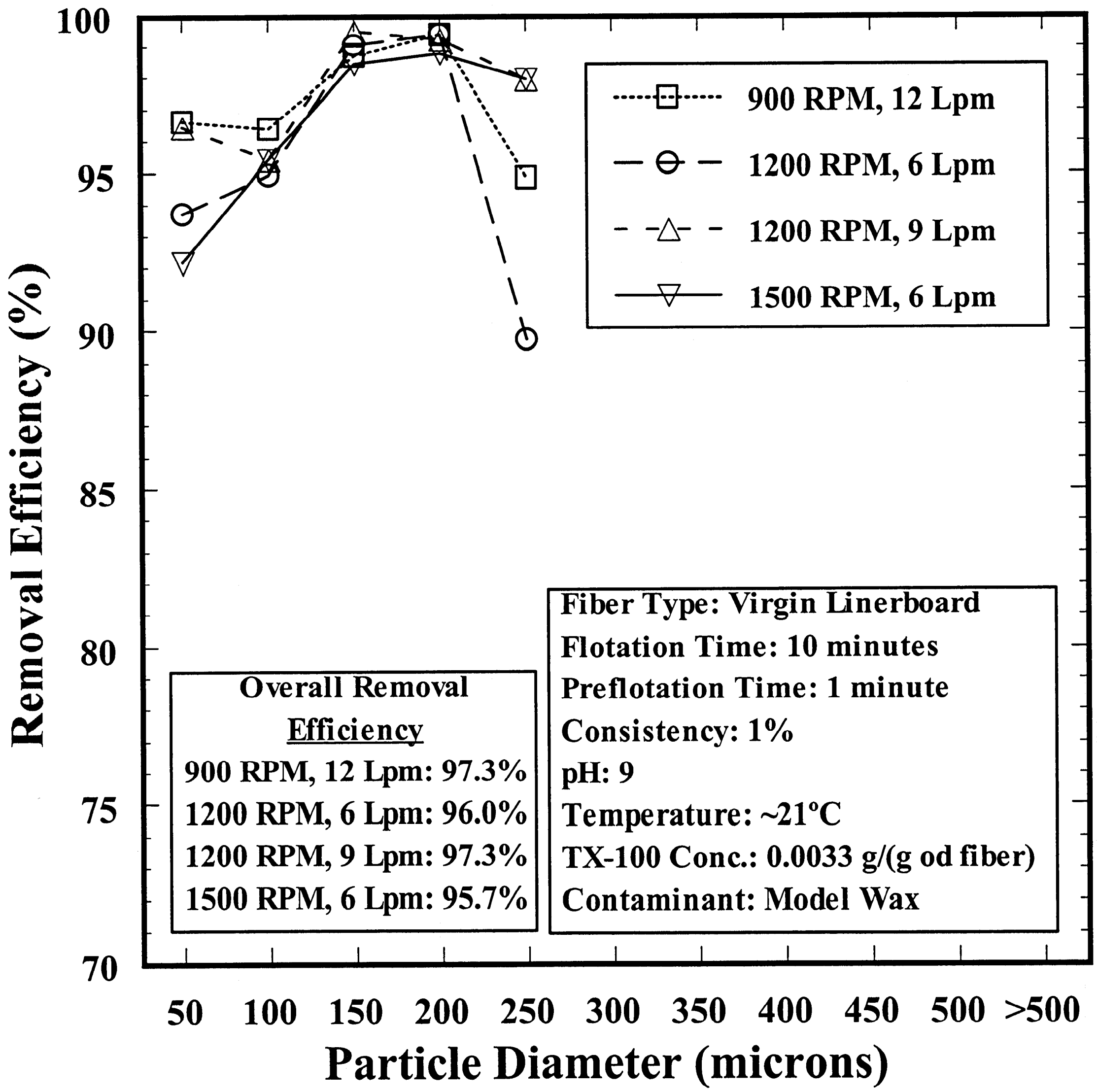
Fiber Loss (%)
15
10
5
0
0
0.5
1
1.5
Fiber Consistency (%)
Fiber Type: Virgin Linerboard
Flotation Time: 10 minutes
Preflotation Time: 1 minute
pH: 9
Temperature: ~21°C
TX-100 Conc.: 0.0033 g/(g od fiber)
Impeller Speed: 900 RPM
Air Injection Rate: 6 Lpm

Figure 6



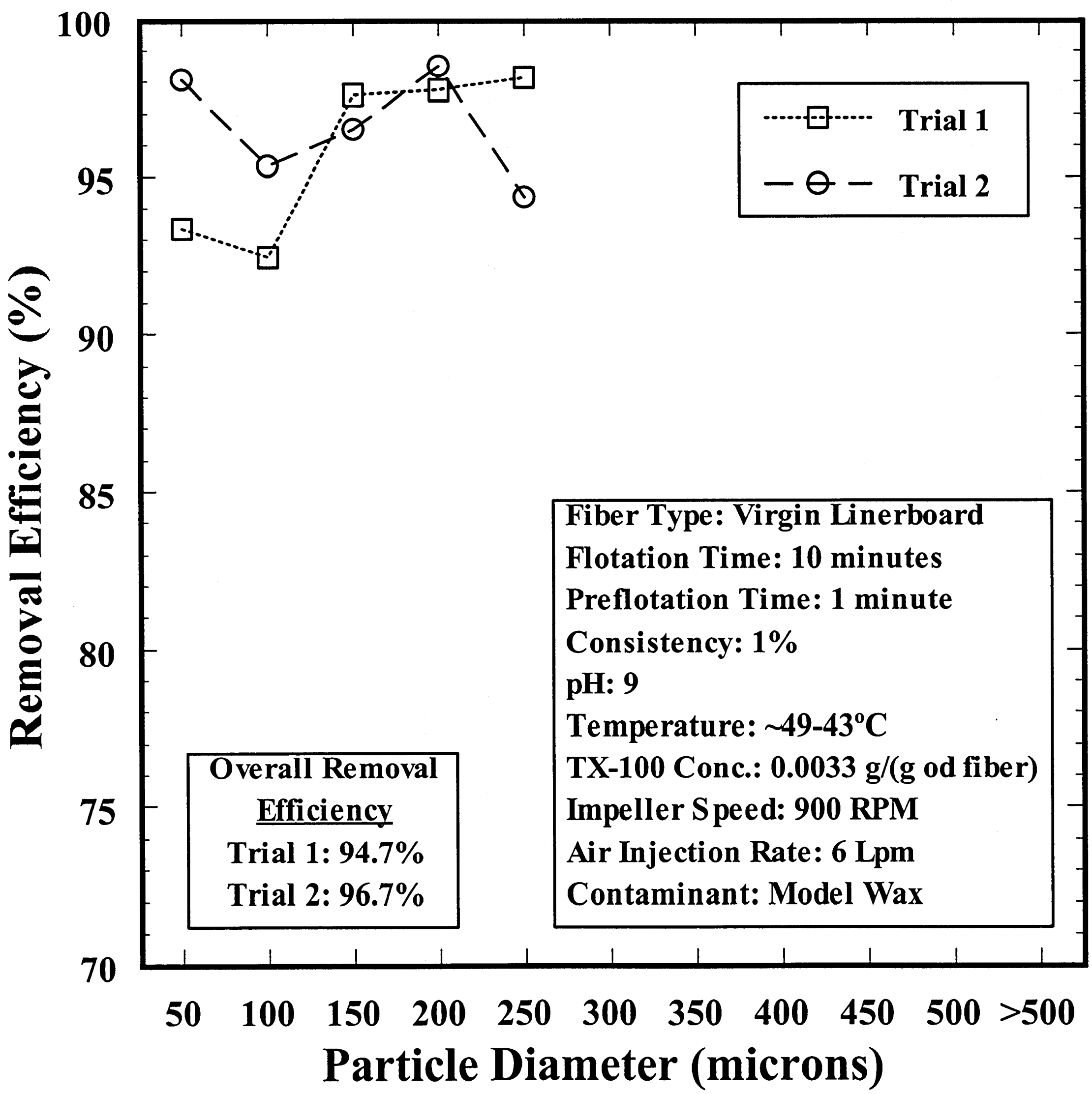
18
16
14
12
10
8
6
4
2
0
Fiber Loss (%)
500
700
900
1100
1300
1500
Impeller Speed (RPM)
12 Lpm
9 Lpm
6 Lpm
Air Injection Rate
Fiber Type: Virgin Linerboard
Flotation Time: 10 minutes
Preflotation Time: 1 minute
Consistency: 1%
pH: 9
Temperature: ~21°C
TX-100 Conc.: 0.0033 g/(g od fiber)

Figure 7



100
95
90
85
80
75
70
Removal Efficiency (%)
50
100
150
200
250
300
350
400
450
500
>500
Particle Diameter (microns)
900 RPM, 12 Lpm
1200 RPM, 6 Lpm
1200 RPM, 9 Lpm
1500 RPM, 6 Lpm
Overall Removal Efficiency
900 RPM, 12 Lpm: 97.3%
1200 RPM, 6 Lpm: 96.0%
1200 RPM, 9 Lpm: 97.3%
1500 RPM, 6 Lpm: 95.7%
Fiber Type: Virgin Linerboard
Flotation Time: 10 minutes
Preflotation Time: 1 minute
Consistency: 1%
pH: 9
Temperature: ~21°C
TX-100 Conc.: 0.0033 g/(g od fiber)
Contaminant: Model Wax

Figure 8



100
95
90
85
80
75
70
Removal Efficiency (%)
50
100
150
200
250
300
350
400
450
500
>500
Particle Diameter (microns)
Trial 1
Trial 2
Overall Removal Efficiency
Trial 1: 94.7%
Trial 2: 96.7%
Fiber Type: Virgin Linerboard
Flotation Time: 10 minutes
Preflotation Time: 1 minute
Consistency: 1%
pH: 9
Temperature: ~49-43°C
TX-100 Conc.: 0.0033 g/(g od fiber)
Impeller Speed: 900 RPM
Air Injection Rate: 6 Lpm
Contaminant: Model Wax

Figure 9